An Interesting Wave Amplifier*

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Summary—This paper concerns the theory and structure of an plifier involving growing waves.

THIS PAPER discusses an interesting amplifying device which makes use of growing waves that resemble in some ways the waves characteristic traveling-wave tubes, double-stream amplifiers and ne other electron beam devices. The paper first presents theory of amplification, and then discusses the physical vice.

The theory is worked out in terms of a cylindrical minar-flow, single-velocity beam of mass density ρ. The am is assumed to be incompressible and to have an pressure P. Linearized solutions with no variation th angle about the axis are sought. It is assumed that quantities contain a factor as exp $(j\omega t - j\beta z)$, which presses all variations with respect to z and t.

From Newton's laws, we have for the Eulerian velocity mponents v_r and v_z the linearized equations

$$(\omega - \beta u_0)v_z = -(1/\rho)\beta P \tag{1}$$

$$(\omega - \beta u_0)v_r = -j(1/\rho)\,\partial P/\partial r. \tag{2}$$

Because the flow is incompressible, the divergence of e velocity must be zero; thus

$$-j\beta v_z + \partial v_r/\partial r + v_r/r = 0. \tag{3}$$

From (1)–(3), we easily obtain

$$\partial^2 P/\partial r^2 + (1/r)\,\partial P/\partial r - \beta^2 P = 0. \tag{4}$$

he solution of (4), which is finite on the axis, is, where A a constant,

$$P = AI_0(\beta r). \tag{5}$$

We must now consider the boundary condition at the ge of the beam. This boundary will be located at $+ \tilde{r}$, where $\tilde{r}$ is a radial displacement corresponding to We have

$$v_r = j(\omega - \beta u_0)\tilde{r}. \tag{6}$$

rom (6) and (2)

$$\tilde{r} = \frac{-(1/\rho)(\partial P/\partial r)}{(\omega - \beta u_0)^2}. \tag{7}$$

For small displacements, the curvature of the boundary the plane of the axis at $r + \tilde{r}$ is $\partial^2(r + \tilde{r})/\partial z^2$. The urvature in a plane normal to the axis is $-1/(r + \tilde{r})$, which the ac component is $\tilde{r}/r^2$. The ac pressure P the boundary is given in terms of a surface tension S and the total ac curvature, the sum of these two curvatures

$$P = -S(\beta^2 - 1/r^2)\tilde{r}. \tag{8}$$

By using (7), we see that

$$P = \frac{(S/\rho r^2)((\beta r)^2 - 1)\,\partial P/\partial r}{(\omega - \beta u_0)^2}. \tag{9}$$

This must hold at the boundary, $r + \tilde{r}$. To the first order we can take P and $\partial P/\partial r$ as the values at r, as given by (5). Thus, from (5) and (9) we obtain

$$(\omega - \beta u_0)^2 = (S/\rho r^2)((\beta r)^2 - 1)\beta I_1(\beta r)/I_0(\beta r). \tag{10}$$

We now look for growing waves by assuming

$$\beta = \omega/u_0 + \delta. \tag{11}$$

We approximate β by ω/u_0 on the right-hand side of (10) and obtain the approximate expression for δ,

$$\delta = \pm j(S/\rho r^3 u_0^2)^{1/2}(20 \log_{10} e)^{-1} F(\omega r/u_0) \tag{12}$$

$$F(\omega r/u_0) = 20 \log_{10} e[(1 - (\omega r/u_0)^2) \cdot (\omega r/u_0) I_1(\omega r/u_0)/I_0(\omega r/u_0)]^{1/2}. \tag{13}$$

The gain G in db per unit distance for the growing wave is

$$G = (S/\rho r^3 u_0^2)^{1/2} F(\omega r/u_0). \tag{14}$$

In Fig. 1, $F(\omega r/u_0)$ is plotted vs $(\omega r/u_0)$. We see that for low frequencies, the gain is proportional to frequency, and that it reaches a maximum of about 3 near $\omega r/u_0 = 0.7$ and falls to zero at a frequency f_m given by

$$f_m = u_0/2\pi r. \tag{15}$$

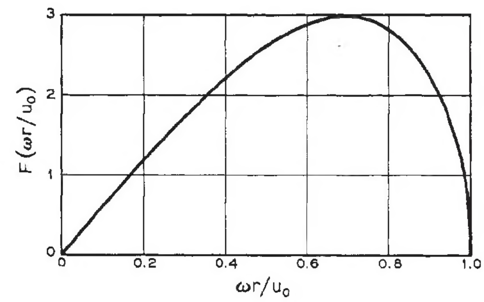

Fig. 1.

Let us now consider the actual device. This is an acoustic amplifier attributed by Boys in a lecture given on January 3, 1890[1] to Mr. Chichester Bell, cousin of

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[1] C. V. Boys, "Soap Bubbles," Doubleday & Company, Inc., New York, N. Y.; 1959.

Alexander Graham Bell, inventor of the telephone. I know of no earlier wave-type amplifier.

In this amplifier, a thin jet of water is directed against a small rubber diaphragm which is coupled to a horn. Any wave on the stream of water causes the diaphragm to vibrate and produces a sound from the horn. It appears that growing waves set up in the stream of water by touching a tuning fork or a music box to the nozzle from which the water flows can produce a volume of sound from the horn sufficient to be heard through a lecture hall.

It is not the purpose of this paper to deal with the excitation of the growing waves by the vibration of the nozzle or with the vibration imparted to the diaphragm by the stream of water. It is interesting, howeve consider a numerical example.

Suppose that we assume a stream diameter of 1/10 and require a cutoff frequency of 5000 cps. Then f (15) we see that we must have a stream velocit 1570 cm/sec. This corresponds to a head of 1260 cn 12.6 meters (or about 41 feet).

The maximum gain G_m in db/cm, which in this will occur at a frequency of about 3500 cps, is very ne

$$G_m = 3(S/\rho r^3 u_0^2)^{1/2}.$$

For the example given above, we already have r and For water, S is about 73 dynes/cm and ρ is about gram/cm^3. Hence, G_m will be 1.43 db/cm.

High Average Power Dissipation in Helix Tubes*

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Summary—By precisely shrinking the glass envelope around the helix to a controlled depth, thus providing an exceptionally low thermal impedance to the outside of the envelope, and passing a suitable coolant over the envelope, it has been found that the power dissipation capability of helix circuits can be extended by more than one order of magnitude. A qualitative analysis indicates that the heat transfer characteristics should be as good as the experimental results indicate.

BY precisely shrinking the glass envelope around the helix to a controlled depth, thus providing an exceptionally low thermal impedance to the outside of the envelope, and passing a suitable coolant over the envelope, it has been found that the power dissipation capability of helix circuits can be extended by more than one order of magnitude.

This presents the possibility of an entirely new class of power tubes, moving into an area that has been heretofore the domain of the "all-metal circuits." It will be especially useful in electronic counter-measures systems, where bandwidth is crucial and the average power demands are already beyond the state of the art for helix circuits. It will also be useful in bifilar helix, electrostatically focused tubes where power output is limited by the intercepted beam handling capacity of the circuit.

In tubes, as presently designed, performance can be optimized by good gun design. However, there appear to be two major limiting factors, RF losses and RF defocusing. This condition is exaggerated at high peak powers and is further complicated by angular magn field variations due to slots in the pole pieces for coupl

A satisfactory solution to the power dissipation probl demands that the characteristics of the helix be affe minimally by the cooling scheme. This implies that dielectric loading be kept within acceptable limits, that no conducting material be brought so close as adversely affect the RF properties of the helix.

In a vacuum, there are two ways to cool a helix; is by conduction, and the other by radiation. Radiat cooling is undesirable for two reasons. As the helix te perature increases, the helix becomes more lossy, t causing the output power to drop until equilibrium reached. Also, this radiating helix acts as a heat element to out-gas those parts of the tube to which radiates. As a consequence, the life expectancy of th tubes will be much shorter than if they were run c

Design

In designing a tube that is to handle apprecia average power, the circuit is generally made of a mate with as high a thermal conductivity as is available. I example, in "all-metal circuits," this is usually copp However, examination of the heat flow equation ΔQ $k\ dA/dL\ \Delta t$ indicates that there is another way to op mize heat flow, and that is by the geometry.

Thus, any decrease in conductivity k can be offset an increase in the geometry factor A/L. Indeed, exami tion of helix-glass envelope structure indicates that geometry factor A/L is quite large. The helix and envelo used in this experiment were those used in the Hug Products, MAS-1A, S-band, 1 kw, 2 − 4 kmc amplifi

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